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The key technologies and development of offshore wind farm in China

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ABSTRACT

China is one of the largest energy consumers in the world. Excessive consumption of coal and other primary energy causes serious environmental pollution and energy crisis. China must wean from the over-reliance on coal and needs to make great efforts to develop clean and efficient renewable energy. In recent years, offshore wind energy has been developing rapidly with the advantages of not taking up land resources and high utilization rate. By the end of 2012, the total installed capacity of offshore wind power was 389.6 MW in China. The planning capacity will be 5 GW by 2015 and 30 GW by 2020 [1,2]. Compared to onshore wind power, the development of offshore wind power is facing some new problems and challenges, for example power transmission, offshore harsh natural environments, multi-sectoral coordination and management, and so on. This paper firstly analyzes the irrationality of China's energy consumption structure and the necessity for developing offshore wind power. Secondly, an overview of offshore wind farm access, AC (Alternating Current) and DC (Direct Current) transmission technologies and offshore wind turbine control strategies are given. The development status and future plans of offshore wind power are also introduced. Finally, we analyze the existing problems and obstacles during the construction process of offshore wind farms from three aspects, including technical, economic, and national policies. And some corresponding recommendations to accelerate the development of offshore wind farm are also proposed.

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1. Introduction

China's rapid economic development requires a lot of energy consumption. Coal is the first choice with the advantages of abundant resources and cheap price. Primary energy structure is dominated by coal, which is the main feature of China's energy structure. In recent years, despite the increase use of hydropower and other renewable energy sources, the proportion of coal consumption in the energy structure is still too high. The proportion of various energy consumptions of China in 2013 (from Jan. to Dec.) is shown in Fig. 1 [1,2]. The coal consumption is 3.76 billion tons, accounting for 65.7% of the total primary energy consumption. However, the world's coal consumption average proportion accounted for less than 30% of the total primary energy [3,4]. In the developed countries such as the United States and Japan, the proportion is less than 25% [5,6]. The consumption proportion of high-polluting fossil energy such as coal is too high in China, much higher than the developed countries, even higher than that of some developing countries, such as Brazil, India [2]. So China's energy structure is unreasonable. Meanwhile, because of the relatively low proportion of oil, gas, hydropower, wind power, solar and other kinds of clean energy in China, the energy consumption intensity is slowly declining. In 2013, China's elasticity coefficient of energy consumption (a ratio of China's energy consumption growth rate in to the economic growth rate) was 0.6 and energy consumption intensity decreased by 3.7% compared with last year. Energy consumption of each ten thousands yuan GDP is 0.737 t of standard coal [7]. Therefore, energy saving and emission reduction are the key problems, and the energy structure needs strategic adjustment.

China is committed to change the energy structure because of the pressure induced by huge energy consumption and the ecological environment. In recent years, China's renewable energy development is fast. According to the national energy administration monitoring data, the total national wind power installed capacity of China (excluding Taiwan) is 77160 MW in 2013. In the aspect of solar energy, national photovoltaic power installed capacity has reached 17,160 MW by the end of 2013 [8]. The PV growing speed is faster than all the other countries of the global. In addition, the development and utilization of biomass energy have also made great achievements. “China's Energy Policy (2012)” White Paper, released in Oct. 2012, proposed to speed up the R&D (research and development) of the core technology for shale-gas exploitation and achieve the overall goal of national yield reaching 6.5 billion cubic meters in 2015. Meanwhile, the target that non-fossil energy consumption accounts for 15% of primary energy by 2020 was also proposed [9]. To sum up, the wind power development enjoys a good momentum growth, and shows good prospects for development. But the onshore wind power development is near saturation and offshore wind power has become the new trend. By the end of 2013, the global offshore wind power cumulative installed capacity is about 7100 MW [10]. China Wind Energy Association statistics showed that there were 11,409 sets of new installed wind turbines, the increased installed capacity of 17,631 MW in 2011 China (excluding Taiwan). Compared with 2010, it decreased by 6.85% (the increased installed capacity was 18,928 MW in 2010), and that was the first negative growth in new installed capacity of nearly 10 years. At the same time, the National Energy Administration issued “about giving the authorization notice of the second batch of wind power projects during the12th Five-Year Plan”. It shows that the total authorized capacity of the second wind power projects is 14,920 MW, reducing 13,910 MW compared with the planning approval released in August 2011, the decreasing amplitude is approximately 50%. This shows that the rhythm of wind power industry development is limited in China. The traditional onshore wind is of depression and the Chinese market is almost saturated. But offshore wind power is still listed as one of the development priorities in “the 12th Five-Year Plan”. Therefore, the development of offshore wind power will be the future trend. It will become the new battlefield of enterprise competition.

Based on the above situation, the paper discusses the related technologies and development of offshore wind power in China. Firstly, the basic control principles of offshore wind turbines based on permanent magnet synchronous motor (PMSM) and doubly fed induction generator (DFIG) are introduced. After that, some key technologies of offshore wind power are summarized, including offshore wind farms grid integration, technical requirements for accessing and wind power prediction, especially including high voltage direct current transmission based on voltage source converter (VSC-HVDC) and low voltage ride through (LVRT) technology for offshore wind farms. Then, Chinese offshore wind power development and future prospects are introduced. Furthermore, due to the harsh natural environment at sea, offshore wind turbines are facing new technical challenges, for example, the impacts of typhoons, ice and salt-spray corrosion, which are described in detail later. Also, they enhance the requirements of wind turbines manufacturing technology and make the maintenance of offshore wind farms difficult. Finally, some appropriate development proposals are given for the difficulties existing in the first round projects bidding of China's offshore wind power, on the aspects of national policy and economy.

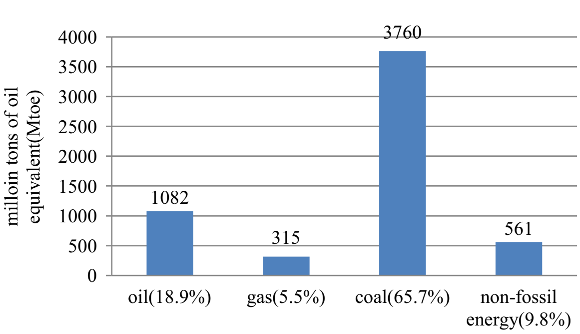

Fig. 1. China's energy consumption structure in 2013.
Source: Authors'adaptation based on [2].

2. Technologies of large-scale offshore wind turbines

China has already had the ability to design and manufacture large-scale offshore wind turbines. Hoisting and trial operation for 6 MW offshore wind turbines have been completed. “the 12th five-year special plan of wind power technology development” formulated by

National Ministry of Science and Technology includes the key technologies research and development of high power wind turbines, such as "10 MW wind turbine overall design technology", "3–5 MW permanent magnet direct drive (PMDD) wind turbine industrialization technology", "7 MW-class wind turbine development and industrialization technology". Large-capacity wind turbine technology has become the focus of China's wind power industry scientific and technological innovation. China intends to invest for R&D of 10 MW wind turbines through "863 plan". The technologies of PMDD, DFIG or superconducting may be used.

The wind turbine is composed of several parts, on the whole, including wind wheel, cabin, tower and foundation. The control system of wind turbines is a core part. It mainly includes the functions such as pitch control [11], speed control, maximum power point tracking control [12], power factor control, yaw control [13,14], start and stop control, monitoring and protection [15]. The performance of the control system directly affects the state of the wind turbine, power generating capacity as well as equipment safety. The control unit will vary for different types of wind turbines, mainly including fixed pitch control and variable speed constant frequency (VSCF) control with variable pitch.

2.1. Control of fixed pitch wind turbine [16]

Induction motor is usually directly connected to the AC grid with fixed pitch control mode. So the speed keeps approximately constant and the pitch angle should be immutable when running. When wind speed below the rated value, wind energy utilization factor is low because of immutable rotational speed; when above rated wind speed, the output power is limited by adjusting the stall performance of blades. This process is simple for control and soft cut-in for turbine is the key technology. The control method of thyristor phase shift soft cut-in can be used for three-phase squirrel cage induction generator. Main purpose is usually to limit the surge current, less than 2 times of the rated current. The inputs of control system include root mean square (RMS) value of current, phase shift angle and the rotational speed of generator, and the outputs are the given value of phase shift angle and bypass signals, as shown in Fig. 2.

2.2. Control of VSCF wind turbines

VSCF wind turbines are based on full-power converter. The pitch angle is adjustable when running. The inherent and dynamic characteristics of generator can be isolated with grid by the full-power converter, effectively. Thus, the electrical frequency of generator can vary with the wind speed and achieve variable-speed operation. This can maintain an approximately constant optimal tip speed ratio and obtain the highest wind energy utilization factor with constant grid frequency. This type of wind turbine can run with gearbox or without gearbox. Different types of generators can be used, generally including DFIG, PMSM, and so on. The control system structures are introduced briefly as follows.

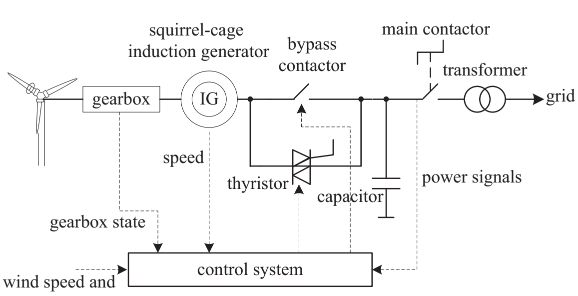

Fig. 2. Control structure of soft cut-in for three-phase squirrel cage induction wind generator.
Source: Authors′elaboration from [16].

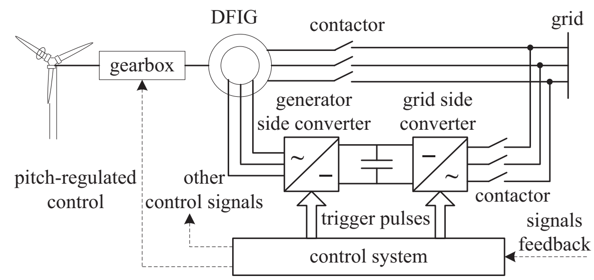

Fig. 3. Control structure of wind turbine based on DFIG.
Source: Authors′elaboration from [17–22].

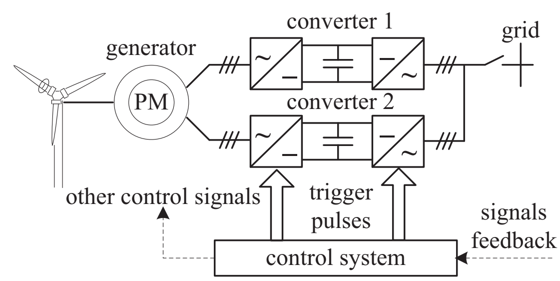

Fig. 4. Control structure of wind turbine based on PMSM.
Source: Authors′elaboration from [23].

(1) Control of VSCF based on DFIG
The control structure of wind turbine based on DFIG is shown in Fig. 3. The stator is connected directly to the grid and the rotor is connected by converter. AC excitation is controlled by the full-power converter to keep the output frequency and voltage of stator being constant. The full-power converter is composed of two VSCs and they work independently. The main functions of the grid side converter are to control power factor and maintain DC voltage constant during transient- and steady- state. The rotor-side converter is mainly used to realize VSCF and decouple the active and reactive power by changing the frequency and amplitude of the excitation current. Conventional control strategies used for DFIG include vector control based on field-oriented (FOC) [17,18], direct torque control (DTC) [19,20], and direct power control (DPC) [21,22]. The main advantage of the DFIG wind turbine is that the rated power of rotor side converter can be only 1/3 of the generator's.

(2) Control of VSCF based on PMSM [23]
PMSM wind turbine can run without speed-increase gearbox. As shown in Fig. 4, multi-pole PMSM is usually adopted. All the output power of the wind turbine is transmitted to grid by converters 1 and 2. The PMSM is a 6-pole generator. The two outputs of the generator are electrical isolation with each other. So, the inputs of converters 1 and 2 are independent. The two converters are parallel-connected and this structure can increase the power rating. The control mode of converter is similar with the DFIG's. DC voltage and active power are controlled respectively by grid- and generator-side converter. The reactive power outputs of both ends are adjustable, so a wider range of generator speed can be obtained.

3. Accessing technologies for offshore wind

Offshore wind farms usually run at 33–36 kV. Whether to establish offshore substation for improving the transmission voltage grade, mainly depends on the size of the wind farm, the distance to shore and the voltage level of the point of common coupling (PCC) [24]. For small offshore wind farms near coastline, AC transmission is usually adopted; for large-scale ones far away from coastline, VSC-HVDC technique is used. Considering the randomness and instability of wind energy, in order to improve the accessing capability of the grid for wind farm and ensure the stability of the power system, State Grid Corporation of China (SGCC) proposes some technical standards for wind farms grid integration. The accessing ways and technical standards mentioned above are all necessary technologies to ensure further large-scale development of wind farms, which are outlined below, respectively.

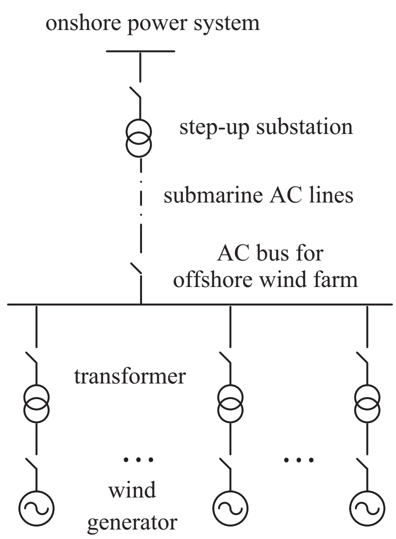

Fig. 5. The AC accessing way for small offshore wind farm grid integration.
Source: Authors′elaboration from [24].

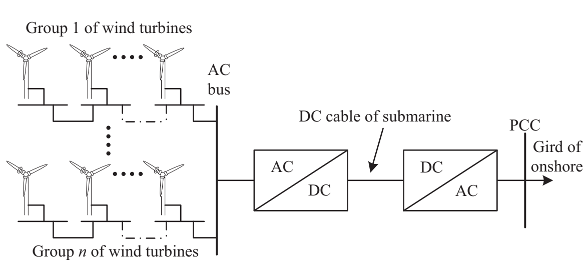

Fig. 6. Topology of VSC-HVDC systems for grid connection of offshore wind farms (SISO).
Source: Authors′elaboration from [25].

3.1. Accessing ways

3.1.1. Small-scale offshore wind farm accessing ways

The costs for offshore substation are exorbitant, especially the support structure and installation costs being much higher than the electrical equipment's. So offshore substations should be avoided to build and AC transmission is usually used. A box-type transformer is configured for each wind turbine to increase its exports voltage to 35 kV. The 35 kV output is connected to the AC bus of wind farm and then to onshore substation through submarine cable. As shown in Fig. 5.

3.1.2. Large-scale offshore wind farm accessing ways

Generally, offshore substation should be built for large-scale offshore wind farm of more than 100 MW and distance more than 15 km away from the coast, especially voltage higher than 36 kV. And VSC-HVDC technique is usually adopted for power transmission. Meanwhile, this has resulted in higher requirements on the miniaturization of electrical equipment and performance of pollution prevention. Flatbed structure is usually adopted for offshore substation and modular structure for electrical equipment. First, they are assembled on the shore, and then hoisted using large offshore installation vessel.

According to the different locations and distributions of offshore wind farms, single-port, multi-port VSC-HVDC systems can be used for power transmission. Take single-input single-output (SISO) structure as an example for simplicity, as shown in Fig. 6 [25]. All wind turbines are connected to the same AC bus. After AC/DC conversion with one offshore high-power converter, it is connected to onshore converter station. After DC/AC conversion with a converter the same as the offshore one, it is connected with the grid.

3.2. VSC-HVDC technology

3.2.1. VSC-HVDC technical overview

The principle of VSC-HVDC is shown in Fig. 7. The VSCs are used for offshore and onshore converter stations with same topology. T_1 and T_2 are transformers which can provide commutation reactance between the VSC and grid. Yn-Y or Yn-△ connection is commonly used in practical engineering. It makes one of the both sides be ungrounded system for eliminating the zero sequence components between the converter and AC system. T_1 is usually the step-up transformer of offshore. It can increase transmission voltage and reduce losses, providing appropriate operating voltage for converter, to ensure its maximum output of active and reactive power. T_2 can supply AC secondary-side voltage matched with the DC voltage according to the voltage of accessing grid. It makes VSC converter station work at the optimum operating range. The DC capacitor is used for buffering the inrush current of bridge arms when switching. And it can also reduce the voltage harmonics of the DC side and provide voltage support for the station at both ends.

DC transmission lines are the link of offshore wind farms and grid. Currently, undersea DC cable is usually used in ABB's

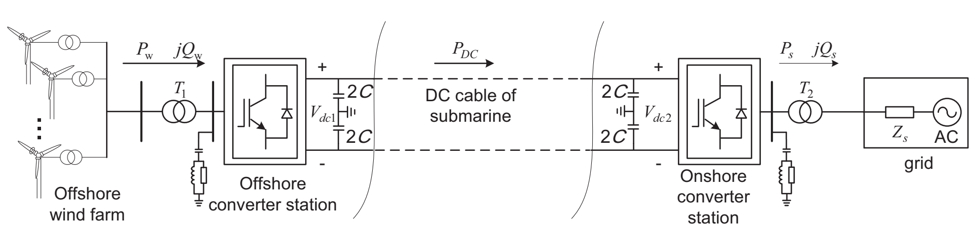

Fig. 7. Basic schematic diagram of VSC-HVDC for offshore wind farm.
Source: Authors′elaboration from [1,40].

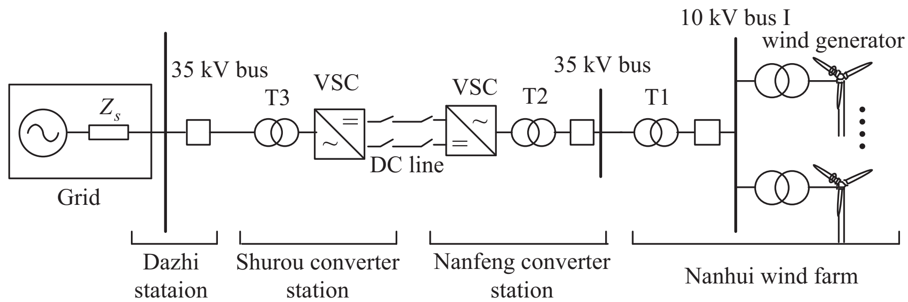

Fig. 8. Access scheme of Nanhui wind farm.
Source: Authors′elaboration from [29].

operating projects. It can meet the requirements of environmental protection in the aspects of noise, harmonic distortion and electromagnetic fields. There are two kinds (1200 mm^2 and 1400 mm^2) of DC cables, which can be chosen depending upon their applications. The single-core conductor of the aluminum or copper is generally used. Since there is no need to change the polarity of the voltage, the polymeric insulating materials can be used, instead of the traditional oil impregnated paper insulation. This kind of DC cable can be processed into armored one with galvanized steel wire, which improves its mechanical strength and makes it to bend repeatedly. So it is more suitable for the deep-sea transmission [26].

Converter stations at both ends are the core components of the HVDC system. Remote control or automatic control can be selected according to the operating conditions and there is no communication needed between stations. Bridge arms of converter are composed by high power full-controlled power electronic devices, such as insulated gate bipolar transistor (IGBT) with anti-parallel diodes. However, the voltage rating of individual full-controlled switching devices, such as IGBT, is low compared to the required converter DC voltage. Thus, the bridge arm composed of series-connected multiple switches and multi-level technology are two effective ways to improve the capacity of VSC. For conventional two- and three-level converters, each arm is named a valve, which is composed by series-connected multiple valve segments. And the valve segment is composed by series-connected multiple valve layers. The valve layer is composed of pressure contact IGBT, drive circuit, heat sinks and other auxiliary circuit [27]. For multi-level topology, modular multilevel converter (MMC) is usually used for the HVDC system [28]. MMC valves are composed of multiple IGBT sub-modules. There are two IGBTs connected with half-bridge structure in each sub-module. The MMC removes the need of switches to be directly connected in series and reduces the difficulty of main circuit designing with improved reliability.

3.2.2. The applications of VSC-HVDC technology in China's offshore wind farms

VSC-HVDC technology has been studied in China since 2000. The VSC-HVDC projects which are completed or under construction mainly include China-Shanghai Nanhui VSC-HVDC demonstration project, Dalian cross-sea VSC-HVDC demonstration project, the Nan-ao VSC-HVDC project of Guangdong province and the Zhoushan multi-terminal VSC-HVDC demonstration project.

(1) China-Shanghai Nanhui VSC-HVDC demonstration project is the first VSC-HVDC project of China. It was successfully completed and started its trial operation in Mar. 2011 [29]. The converter stations at Nanhui wind farm can realize dynamic voltage support, reactive power compensation, and DC power transmission. The scheme is rated at 18 MW with DC voltage of ± 30 kV and DC current of 300 A. The Length of the DC cable is 8.6 km. As shown in Fig. 8, the wind farm output is connected to the 10 kV bus at Nanhui wind farm station, and is then stepped up to 35 kV. The Nanfeng converter station is then connected to this bus and its DC is connected to the Shurou converter station through DC lines. After DC/AC conversion in Shurou station, it is connected to 35 kV bus at the Dazhi station.
(2) The cross-sea VSC-HVDC demonstration project being constructed in Dalian, started in July 2012. It is scheduled to become operational by the end of 2016. The capacity is 1000 MVA and the DC voltage is ± 320 kV. The total DC cable length is about 54 km with 35 km of submarine cable. The total investment for the project is expected to reach 5.1 billion Yuan. The sending end converter station locates at Jinjia area of Dalian, which is an extension project based on Huai river 220 kV substation. The receiving end converter station is at Donggang area of Dalian south, which is connected with Gangdong and Qingyun substation through two group lines, respectively. The VSC-HVDC system can operate with two modes. One is active mode, the other is reactive mode. When the system is running in active mode, the transmission capacity of the Dalian urban grid can be strengthened. When in reactive mode, If the AC transmission channel between Dalian southern grid and the main grid was to be completely disconnected (for example, tower collapses), the southern grid would run as an “isolated island”, and all the power would be only supplied from the VSC-HVDC system. So, this mode can enhance the power supply reliability and transmission capacity in Dalian central area, eliminating security risks of the grid [30].
(3) The Nan-ao VSC-HVDC transmission project started in Apr. 2012. As a demonstration project supported by the national 863 project, the DC side voltage is ± 160 kV and the transmission capacity is 200 MW. Both new VSC-HVDC converter stations are built near the original 110 kV Jinniu station and Qing-ao station in Nan-ao Island, respectively. The outputs of Niutou Hill, Yun-ao and Qin-ao wind farms are connected to Jinniu and Qing-ao stations for AC/DC conversion. Then, the DC power brings together at Jinniu station and is sent out through the new DC overhead cables of this island. The overhead lines are replaced by submarine cables when being away from the island and connected with Suliu station. After DC/AC conversion, it is connected with Shantou grid. The project will achieve large-scale wind power on the island grid integration. The investment of the entire demonstration project is 1188 million yuan and it was put into operation in December 2013 [31].
(4) Zhoushan multi-terminal VSC-HVDC demonstration project is the first five terminals HVDC engineering of the world. Feasibility study report of the project has been passed. The DC voltage is ± 200 kV. Five converter stations in total will be constructed in Dinghai, Daishan, Qushan, Yangshan and Sijiao, and their capacity are 400 MW, 300 MW, 100 MW, 100 MW and 100 MW, respectively. The length of DC cables is 141 km. The locations of 5 converter stations and the paths of AC and onshore DC lines have been determined. The engineering feasibility assessments for these programs have been completed by

SGCC. Zhoushan power supply bureau will be responsible for the implementation of the pre-construction work [1,32].

3.3. Technical requirements for offshore wind farm grid integration

3.3.1. Requirement of low voltage ride through

SGCC published an enterprise standard "Technical requirements for wind farms connected to the grid" in 2009. Currently, offshore wind farm grid integration is also performed according to this standard. It gives a detailed specification of technical performance and conventional control objectives such as active power, frequency, reactive power, power quality, and so on. In addition, a new requirement of the wind farm LVRT is added.

If the capacity of wind power is small, generally, wind turbines could be removed from the grid when grid fault and voltage sags occur. However, with the increase in the proportion of wind power grid integration, wind farm off-grid is no longer an appropriate strategy when grid fault happens, and it even may accelerate grid islanding. It is needed that wind farms can ride through grid fault. Reactive power should be provided to help grid recovery during the fault. And it can be automatically transferred to the normal operating state after fault recovery. LVRT is necessary for the security and stability of the local and entire grid. So it has become one of the main concerns of the grid dispatching departments.

Fig. 9 is the LVRT operating range of wind farm. The LVRT curve includes instantaneous voltage drop, the minimum voltage holding time and the voltage recovery. It depends on the actual analysis of the wind farm grid integration. As shown in Fig. 9, when voltage at PCC of wind farm drops to 20% of the rated, the wind turbines must keep continuous operation for 625 ms (milli second) before off-grid. If PCC voltage of wind farm can restore 90% of the rated voltage within 2 s after failure, wind turbines would still be in operation rather than off-grid [33].

3.3.2. Output power prediction of wind farm [34]

The output power prediction system of wind farm should be configured according to the requirements of "technical standards for wind farm grid integration (revised)". It should be able to achieve the functions of 0–48 h short-term and 15 min to 4 h ultra-short-term wind power prediction [35]. Meanwhile, the data processing functions such as storage, delivery and web publishing, view and reporting are needed. Database system and related communications systems should be also equipped. The specific requirements are as follows.

(1) Wind farm can automatically report the future 15 min to 4 h forecasting curve of power generation to grid dispatching departments every 15 min. The time resolution of the predicted value is 15 min.
(2) Wind farm can provide 0:00–24:00 pm power forecasting curve of the next day at the predetermined time of grid dispatching departments. The time resolution of the predicted value is also 15 min.

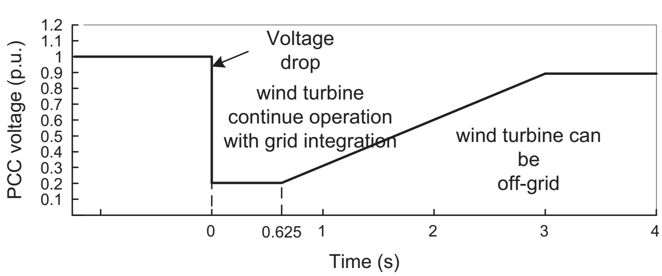

Fig. 9. The operating range of LVRT for wind farm.
Source: Authors'elaboration from [33].

The wind power prediction system is generally divided into 4 modules, including the mesoscale numerical simulation system, micro-scale meteorology model, physical model of power generation and error statistical correction model. As shown in Fig. 10, in which MOS is used to obtain physical model of power generation by modifying multi-scale model output results with statistics.

4. China's offshore wind power development

In recent years, China's wind power industry develops rapidly. But onshore wind power is limited by land and other resources, becoming saturated gradually. Offshore wind power becomes a new development direction with many advantages, such as offshore abundant wind energy resources, long annual utilization hours, high wind speed, steady and sustained wind resource, high generating capacity, no land constraints, and smaller impacts on visual and noise, and so on.

4.1. Development overview and distribution of offshore wind power in China

There are very rich offshore wind energy resources in China. Offshore wind energy resources are mainly concentrated in the southeast coast and the nearby islands, and the effective wind power density is more than 300 W/m^2. At 5–25 m water depth and 50 m height, offshore wind power development potential is about 200 GW. At 5–50 m water depth and 70 m height, offshore wind power development potential is about 500 GW. So there are broad prospects for the development and application [36]. By 2011, the global total installed capacity of offshore wind power was 3980 MW, with 209.9 MW in China. And in China's "The 12th Five-Year Plan", offshore wind power is one of the development focuses. According to the preliminary provincial statistics of offshore wind power development plan, the cumulative installed capacity of offshore wind power in China is expected to reach 5 GW by 2015 and 30 GW by 2020, with 17.7 GW offshore and 5.1 GW inter-tidal [1,37]. Jiangsu and Shandong provinces will be the focuses of the coming offshore wind bases' development and construction, and the constructions will be propelled in many provinces, including Hebei, Shanghai, Zhejiang, Fujian, Guangdong, Guangxi, and Hainan. The specific distribution is shown in Table 1 [38].

From the planning of these provinces and cities, the largest offshore wind potential growth will locate in Jiangsu and Shandong. There is nearly 1000 km coastline in Jiangsu province and its coastal

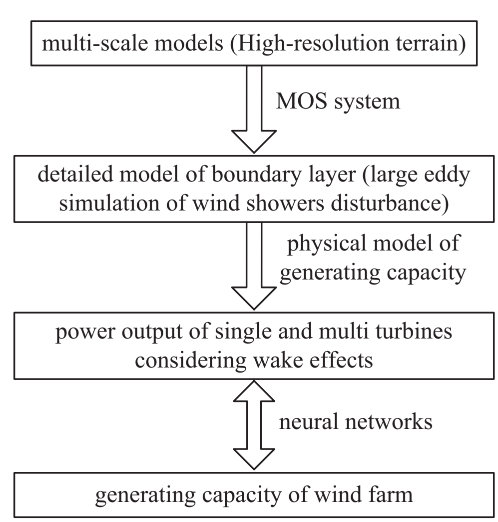

Fig. 10. Functional modules of power prediction system for wind farm.
Source: Authors'elaboration from [34].

Table 1
Development plan of China's southeast coastal provinces offshore wind power.
Source: Authors′elaboration from [38].

Region	Planned installed capacity/MW					
	2015			2020		
	Intertidal	Offshore	Total	Intertidal	Offshore	Total
Shanghai	100	600	700	200	1350	1550
Jiangsu	2600	2000	4600	2900	6550	9450
Zhejiang	200	1300	1500	500	3200	3700
Shandong	1200	1800	3000	1200	5800	7000
Fujian	100	300	400	300	800	1100
Total	4200	6000	10,200	5100	17,700	2280

shoal land area is accounted for 1/4 of China's total. And there are the world's largest radial sand ridges along north coast of Jiangsu (total area is 190 million mu (a unit of area, =0.0667 ha) above zero meter base-level). These resources provide broad prospects for the development of offshore wind farms in Jiangsu province and it is reported that there are more than 10 offshore wind projects being built.

Qingdao plays a key role for the development of offshore wind power in Shandong province. Qingdao is surrounded by the sea on three sides, with coastline of more than 800 km and accounting for 1/4 of Shandong province. So there are rich offshore wind resources. Last year, “Shandong Peninsula Blue Economic Zone Development Plan” proposed by Shandong province shows that Lubei, Laizhou Bay, Bozhong, Long Island and the north of Shandong Peninsula, offshore wind farms will be completed by the end of “the 13th Five-Year Plan”. And offshore wind power installed capacity will reach 10,000 MW.

Shanghai, as the Yangtze River Delta economic center, has accumulated rich experience in the project of “stage I of East China Sea Bridge wind farm”. During the “the 12th Five-Year Plan”, another two offshore wind farms will be built, being stage II of Donghai Bridge wind farm and Lingang wind farm, respectively. The two projects are being constructed and the Donghai Bridge II is expected to be completed during 2015.

4.2. *The major offshore wind projects of China [39,40]*

Currently, five major offshore wind farms have been put into operation in China:

(1) The Suizhong oilfield test station of China National Offshore Oil Corporation (CNOOC), which is constructed in Nov. 2007 by CNOOC. China's first offshore wind turbine is installed and grid integration on Nov. 28, 2007. Installed capacity is 1.5 MW and wind turbine supplier is Goldwind Science & Technology Co., Ltd.
(2) Donghai Bridge offshore wind power demonstration project, which is the first offshore wind power project for grid integration except the Europe's. In addition, it is the first national offshore wind power demonstration project of China. The total investment is 2.365 billion yuan. Sinovel 3 MW wind turbines are used and the total installed capacity is 102 MW. On Feb. 27, 2010, the installation of all 34 wind turbines was completed. The formal operation for grid integration was realized on July 6, 2010.
(3) Experimental project of intertidal zone in Xiangshui, which is built by the Yangtze New Energy Development Co., Ltd. Hoisting of the first intertidal wind turbine (2 MW turbine of Shanghai Electric Group Company) for testing was completed on Mar. 10, 2010. And the second one (2.5 MW turbine of Goldwind Science and Technology Co., Ltd.) was completed on Mar. 24, 2010. The total installed capacity is 6.5 MW and the future planning capacity is 201 MW, consisting of 67 wind turbines of 3 MW.
(4) Rudong wind farm project of intertidal zone, which is the start-up project of China Longyuan Power Group Co., Ltd. for offshore wind power development plan. The total installed capacity is 32 MW. It realized all power generation to grid in Jun. 2011. The planning installed capacity is 150 MW in the future, consisting of 58 wind turbines of 3 MW, locating at southern yellow sea and the intertidal zone of Rudong sea. This project was approved by the National Development and Reform Commission on Dec. 6, 2010. The first 100 MW are planned to be put into operation in 2011 and all the others put into power generation in 2012.

Large-scale offshore wind projects under planning and construction include

(1) Rongcheng offshore wind project will be built by China Huaneng Group. The total capacity is 102 MW, consisting of 34 wind turbines of 3 MW, and the total investment is 24.2 billion yuan.
(2) Jiangsu Dafeng intertidal zone wind power demonstration project, its capacity is 300 MW, consisting of 100 wind turbines of 3 MW. Offshore linear distance is about 55 km with water depth being 3 to 13 m in the field. The first 200 MW will be completed in stage I of the project. It will occupy a sea area of 130 km^2 and the total investment is 40 billion yuan.
(3) Jiangsu Xiangshui offshore wind farm, its total planning capacity is 201 MW, consisting of 67 wind turbines of 3 MW. The total construction period is about 32 months, with investment of 3.54 billion yuan. The feasibility study report and security pre-assessment report of this project have been passed.
(4) Dalian offshore wind farm project, it is composed of 8 offshore wind farms at the regions of Zhuanghe and Huayuankou. The planning total installed capacity is 2200 MW, with 1600 MW being for Dalian city. Considering offshore wind farm construction investment balance and the limitation of grid accessing capacity for wind farms, only part of Zhuanghe and Huayuankou wind farms will be developed during “the 12th Five-Year Plan” period and the rest will be completed during “the 13th Five-Year Plan” period [41]. And the VSC-HVDC transmission technology will be used, the details are introduced in Section 3.
(5) Xuwen offshore wind power project in Zhanjiang, it is the first demonstration project of offshore wind farm in Guangdong province. The project has been constructing now, and it will be completed during 2–3 years. And the offshore wind farm in Nan-ao island is another recent project of Guangdong province, the detailed descriptions are given in Section 3 [1].

5. Obstacles of offshore wind power development

It is undeniable that the offshore wind power development in China is still at the initial and exploration stage. Overall, the main problems of the offshore wind farm to develop include three aspects, technical difficulties of wind turbine designing and installation induced by harsh natural environment of the sea, problems of development policy and management for offshore wind farm, and the high cost of power generation [42].

5.1. The impact of the harsh environment on the sea

The harsh environment of offshore wind farm, such as salt spray corrosion, large wave force, sea ice impact, typhoon damage and so on, result in higher technology requirements. They cover many disciplines and professions, and thus constrain the development of offshore wind farms.

(1) Impacts of salt spray corrosion on wind turbines
China's southeast coastal regions belong to subtropical monsoon climate. The vapor of containing salt is brought by prevailing land-sea wind. There is a large contacting area between equipment and vapor. This will accelerate the speed of the salt spray corrosion to wind turbines. Wind turbine equipment is made of highly active metallic materials, for example, iron, aluminum, copper. Metal corrosion induced by the salt spray can degrade performance of turbine component, impact its normal operation and even cause major accidents. So in salt spray conditions, offshore wind turbine materials should be treated with preservatives, such as galvanized processing or using stainless steel corrosion-resistant materials.

(2) Impact of typhoon
When wind turbines suffer strong typhoon with wind speed more than the designed limit, some accidents like down tower, bending and line trip may occur. The influences of typhoon on the southeast coast of China are extensive. Its frequency is high, about 1–3 typhoons each year. Typhoon landfall in Guangdong is 3 times a year, accounting for 33% of the total number in China, and 19% in Taiwan, 16% in Fujian, and 10% in Zhejiang. Some developed countries have established their wind characteristics database, e.g., the Froya database in Norway and offshore wind observation database in Canada and the UK. Observational studies of wind characteristics in China are relatively weak, especially lack in the data of strong wind characteristics in the coastal regions. 80% of the typhoons affecting China can form large wave with height more than 6 m. It might have devastating impact on the offshore wind turbines. Overlapping force of waves and typhoons imposes on the foundation of the wind turbine, making great destruction. Therefore, it is necessary to study and evaluate on the impacts of offshore wind turbine foundation induced by typhoon waves.

(3) Risk of floating-ice collision
There are different levels of icing phenomenon every winter, in the offshore of the northern Bohai Sea and Yellow Sea. Icing in northern Liaodong Bay is the most serious sea area in China. In the years of not serious icing situation, this region is covered by 10 cm-thick sea ice within 30 km away from northern coast of Liaodong Bay; while in the years of serious icing situation, 30–40 cm-thick sea ice covers almost the whole sea of more than 70,000 km^2. Collision and extrusion induced by floating-ice may impose on the foundation of wind turbines. The ice frozen around the turbine tower may induce pulling or pressing force on the foundation due to the change of water level. In addition, with the change of temperature, sea ices freeze and thaw repeatedly, that may cause concrete freezing damage. If wind farms are located in icy sea, special design of turbine foundation must be considered for avoiding sea ice collision.

(4) Difficulties of operation and maintenance
Onshore wind farms usually possess their own operation and maintenance center. So, it is convenient for wind turbines to implement maintenance. But for offshore wind farms, due to the harsh natural environment of the sea, for example, salt spray corrosion, typhoon, waves, the failure rate of connecting parts such as bolts is higher. This accelerates the frequency of repairing and maintenance, and increases the maintenance expenditure significantly. When the generator, gearbox, blades and other large parts of wind turbines fail, large crane ship is needed for the disassembly and replacement. And the costs will be much higher. The costs of operation and maintenance for offshore wind turbines are approximately 2–4 times to that of the onshore's. So, it is necessary to design the specialized equipment used for the maintenance and hoisting to facilitate maintenance and repair, which can reduce the construction costs significantly.

5.2. Coordination of government departments

Due to the special location requirements of offshore wind farms and the poor communication between the relevant management departments, the development of offshore wind power is hindered. For the location of offshore wind farm, the National Energy Administration proposed the "Double Ten" standard in 2010. It points out that the location of offshore wind farm should meet the requirements, that is, "Offshore distance should be not less than 10 km and water depth should be not less than 10 m if the width of intertidal flat is more than 10 km". But the National Oceanic Administration did not explicitly indicate which regions can be used. Until July 2011, the National Energy Administration and the Oceanic Administration jointly proposed to implement "Offshore wind power development and construction provisional management regulations". This file gives specific provisions about offshore wind farm planning, pre-feasibility study and the job content of feasibility study. It also put forward the regulations about construction and operation of offshore wind farms. Implementation of this file can avoid sea-using contradiction in different industries and reduce the investment risk of enterprises. However, at the beginning, the departments in charge including National Oceanic Administration and National Energy Administration did not propose a coherent planning policy. This led to re-location of the four offshore wind power concession bidding projects in 2010. None of the constructions has begun. The first round of offshore wind power bidding projects existed for name only [43].

5.3. Cost increasing

Public data shows that offshore wind turbine must be more robust than the onshore to withstand strong wind and seawater. It increases the costs of offshore drilling. Because of away from the coast, its maintenance requires special equipment and conveyance. The additional cost is also needed for the connection between offshore wind farm and land grid. Offshore wind farm per kilowatt investment is about 1.6–1.9 million yuan [44].

Offshore wind farm should be at deep-water location and away from the coast in accordance with the principle of "Double Ten". Obviously, this will result in incremental cost of offshore wind power projects. For many sea regions with water depths greater than 10 m in China, the offshore distance is greater than 10 km, even 50–60 km. This leads to a sharp increase in construction costs of the offshore wind farm, including transformer platform, undersea cable, and so on. The skill requirements of the workers for offshore wind power equipment maintenance are also increased because of the water depth increasing. For a technical staff, such as diving and other underwater operational skills are needed, except for professional equipment maintenance skills. This increases the costs of employing.

However, pool purchase price (PPP) of offshore wind power fails to compensate the high cost. It also faces the difficulty of low PPP. In the first offshore wind power project bidding, the bid price is 0.737 yuan/kWh for the Binhai 300 MW offshore wind farm project of Datang New Energy Co., Ltd., 0.7047 yuan/kWh for the

Sheyang offshore 300 MW project of China Power Investment Co., Commonwealth, 0.6235 yuan/kWh for Dongtai intertidal 200 MW of Shandong Luneng Group company and 0.6396 yuan/kWh for Dafeng intertidal zone 200 MW project [45,46]. It is known, the feasibility study report notes that the PPP of offshore wind power is 1.2–1.3 yuan/kWh. The insiders' conservative estimate is 0.8 yuan/kWh [47]. However, in order to obtain offshore wind farm development rights, the major bidding companies have depressed the price. So, there is no exemplary.

6. Recommendations for China's offshore wind power development

Based on the above summarizing and analysis about present situation, planning, project progress and management policies of offshore wind farm development, suggestions are proposed as follows.

(1) Establish an efficient coordination and management mechanism between offshore wind power departments. Many aspects should be considered during offshore wind farm planning, including shipping, nature reserves, fisheries production, military, and so on. The approval departments in charge for offshore wind farm should include the energy administration, oceanic administration, environmental protection and military branch [38]. The communications between multiple management departments are needed to be strengthened. To make an offshore wind power planning, the timely communications are needed on the aspects of sea usable areas, use function, environment and protected regions with maritime administrations, local planning departments and military branch, in this way, some corresponding adjustments can be made. Because of the differences in compliance rules and law enforcement approaches of multiple departments, efficient coordination and management mechanism should be established to promote offshore wind power development [42].

(2) Explore the financial subsidy policy for offshore wind power in deep water zone. Financial subsidies should be used to encourage the development of offshore wind farm and it can promote the realization of commercial operation. This is also an international common practice. Germany introduced ladder pricing for offshore wind farms and the subsidy for deep sea water zone is much more than the offshore. China should learn from the implementation experience of European financial subsidy policy and explore policies for offshore wind farms in deep water zone according to its national conditions gradually.

(3) Accelerate the R&D of technology and equipment for offshore wind farm. It includes wind turbines, installation and construction, operation and maintenance, and grid integration technology [48]. At the same time, the government should encourage investment in offshore wind power industry. Investment in R&D of offshore wind power technology should be increased and science foundations should be established to promote the cooperation between enterprises, universities and research institutions for the development of offshore wind power equipment.

7. Conclusions

Wind power is the focus of China's new energy development and offshore wind power is the new development trend. China is rich in offshore wind resources and possesses favorable conditions of offshore wind farm large-scale development. In this paper, key technologies of wind turbines control and typical offshore wind farm projects are introduced. From the existing and planning projects, VSC-HVDC will be widely used for offshore wind farm grid integration. The current situation, future planning, and difficulties in the development of offshore wind power projects are analyzed. The problems during planning, construction and maintenance are summarized and corresponding recommendations are proposed.

On the technological aspects of offshore wind power development, LVRT, VSC-HVDC and the difficulties of turbines design and installation induced by harsh environment at sea are included. The large-scale offshore wind farm development project is systematic, which needs accumulation of technology and experience through demonstration projects. The ability of independent research and development of offshore wind turbine equipment must also be paid attention for improvement. These can promote the sustainable development of China's wind power industry.

Related policies for the development of offshore wind farm are needed to be improved. China is currently in the early stages of offshore wind farm large-scale construction. Due to the lack of experience in planning, construction, operations and imperfect policy, it is a normal phenomenon that there are obstacles of offshore wind power development on technical management aspect. There is developmental law for advanced things for appearing mature. With the continuous improvement of construction technology, management system, policy regulations and government supports, the development and construction of offshore wind power will be much faster than before in China.

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